Appendix A

ST. LUCIE ESTUARY AND INDIAN RIVER LAGOON CONCEPTUAL MODEL

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INTRODUCTION

The St. Lucie Estuary (SLE), a major tributary of the Indian River Lagoon (IRL), located on the southeastern coast of Florida, discharges into the IRL and Atlantic Ocean through the St. Lucie Inlet. The estuary encompasses approximately eight square miles (Haunert et al. 1994). The 930-square kilometer IRL also receives major discharges from Taylor Creek, the C-25 canal, Moores Creek, and the Virginia Avenue Canal to the north of the SLE (Woodward-Clyde 1994). The Fort Pierce Inlet provides an additional connection between the Southern Indian River Lagoon (SIRL) and the ocean. No major IRL tributaries exist from the St. Lucie Inlet south to the Jupiter Inlet.

The model boundary for St. Lucie Estuary / Indian River Lagoon Conceptual Model extends south to the IRL Surface Water Improvement and Management (SWIM) boundary at the Jupiter Inlet and north to the St. Lucie County line, which is north of the Fort Pierce Inlet. To include the nearshore reef tract, the model extends three-miles eastward into the Atlantic Ocean. The western boundary includes the open channel headwaters of the North and South Fork of the St. Lucie River and the coastal structures on the C-23, C-24, and C-44 canals (**Figure A-1**).

Extensive urban and agricultural drainage projects in the watershed of the SIRL have resulted in a loss of storage of approximately three inches or 125,000 acre-feet. Storm water runoff has increased from 11.2 to 15.7 inches per year with higher peak runoff rates. Flows to the North Fork of the St. Lucie River historically accounted for 60% of all flows to the SLE, currently only approximately 25% of the runoff flows to the estuary through that historic route. Runoff has increased substantially, from a historic level of 3% to 25%, through the C-23 canal, an artificial connection into the confluence of the North and South Forks of the St. Lucie River. Along with these hydrologic and land use changes has come a 100% increase in phosphorous loading and a 200% increase in nitrogen loading. Major canals in the watershed include the C-23 and C-24, which are part of the Central and South Florida (C&SF) Project. Smaller secondary and tertiary drainage canals cross the landscape and direct storm water runoff to the primary flood control canals. Changes to historic drainage patterns have also occurred around the C-25 canal to the north of the SLE. Flows that slowly made their way through natural wetlands from the C-25 basin to the North Fork of the river now dump directly into the C-25 canal into the area of the IRL around the Fort Pierce Inlet. In addition, the St. Lucie Canal (C-44), which provides both navigation and the release of floodwaters from Lake Okeechobee, provides a link from the SLE to the lake which did not existed historically.

The major effects of anthropogenic changes in the watershed are significant alterations in the timing (excess wet season flows, insufficient dry season flows), distribution, quality, and volume of fresh water entering the estuaries (Haunert et al. 1994). Despite these impacts, the SLE and IRL continue to be important resources, with significant environmental and economic values. Understanding how these systems respond to stress will provide a basis for well informed management decisions on restoration activities.

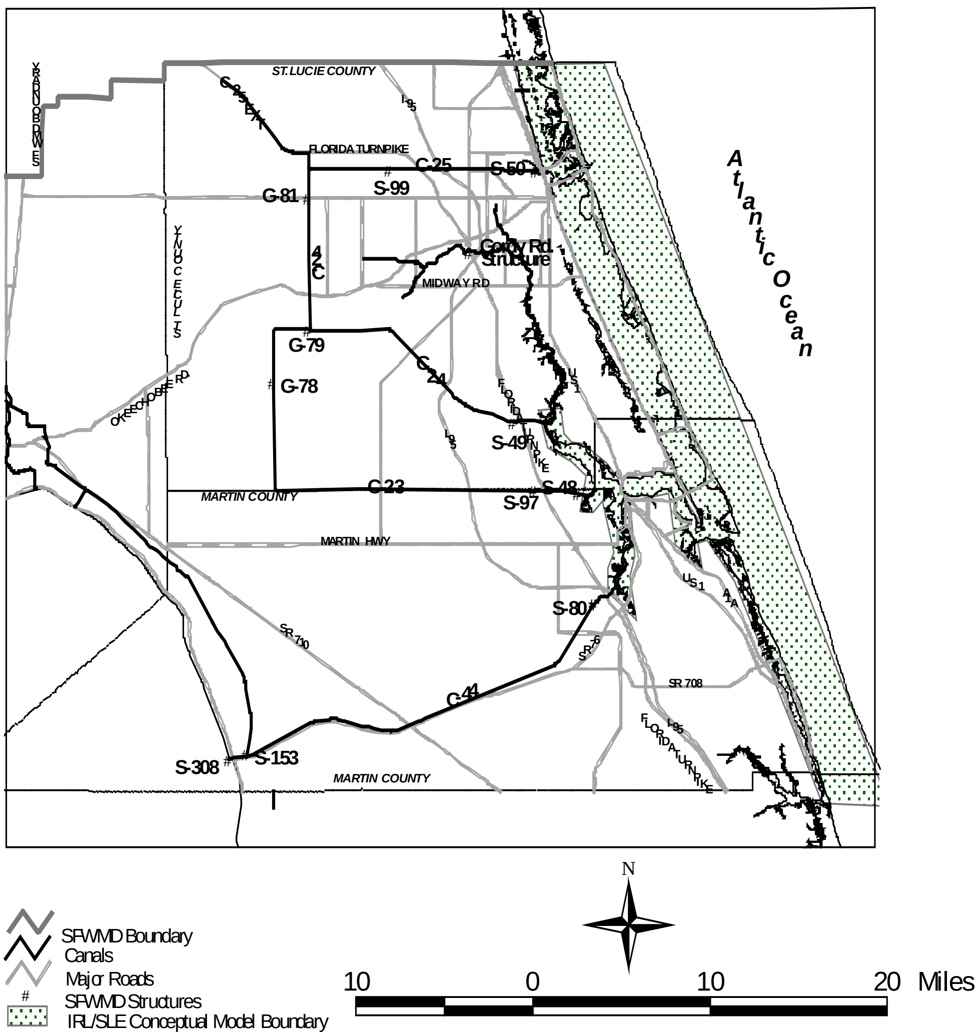

Figure A-1. Indian River Lagoon / St. Lucie Estuary Conceptual Model Boundary

SOURCES

Sources of ecological stressors in the SLE and IRL originate from agricultural and urban development and the ensuing construction and operation of water management systems, both in the local watersheds of the estuary and lagoon and in the larger drainage basin of Lake Okeechobee. Sea level rise is also a factor that effects the ecology of the lagoon system and must be taken into consideration during restoration efforts.

EXTERNAL DRIVERS AND ECOLOGICAL STRESSORS

The sources mentioned above contribute to the resulting stressors on the estuarine and marine ecosystems:

Lake Okeechobee regulatory releases, basin flood releases, and basin water withdrawals result in altered freshwater flow volume and timing. The types of releases and withdrawals are as follows:

When Lake Okeechobee exceeds stages set in its regulatory schedule, water is released from Lake Okeechobee.

Discretionary releases are made from Lake Okeechobee to the SLE to maintain or enhance environmental conditions in the lake.

Basin flood releases are made during wet periods resulting from the combination of the alterations to the local drainage basins and the drainage of agricultural and urban land uses within the basins.

Basin water withdrawals are made during dry periods to fulfill agricultural and urban water demands within the basins.

Nutrients and dissolved organic matter that originate from agricultural and urban land use practices are inputted and are exacerbated by regulatory and flood releases.

Pesticide and herbicide use in the drainage basins have resulted in input of toxins via the canal system and overland flow discharging into the estuaries.

Boating pressure in the area is continuously increasing. Boating represents a significant industry with a rapidly expanding number of boats and support facilities. These facilities can have adverse impacts on water quality and resources of the lagoon.

Fishing pressure began to increase in the 1890s with the development of a commercial industry in the area. With the increase in population presently and into the future, the pressure from recreational fisheries may become the biggest problem.

Physical alterations to the estuary due to inlet construction and maintenance, as well as the development of the shoreline and adjacent wetlands of the estuaries and their tributaries.

ECOLOLGICAL EFFECTS: CRITICAL LINKAGES BETWEEN STRESSORS AND ATTRIBUTES

The overwhelming ecological impact on the SLE and IRL is the alteration of estuarine salinity zonation. Salinity is one of the principal factors influencing the distribution and abundance of organisms inhabiting estuaries (Kennish 1990). Changes in the distribution, timing, and rapidity of change of salinity include low salinity events, due to basin and Lake Okeechobee regulatory water releases, and hypersalinity events, due to excessive basin water withdrawals and drought conditions.

Accompanying the regulatory water releases is the transport of massive volumes of organic and inorganic sediments, which contribute to the deposits of ooze and muck in the estuaries (Shrader 1984, Gunter and Hall 1963, Pitt 1972). The large accumulations of muck covering the bottom of the estuary dramatically decrease the quality and quantity of habitat for everything from benthic macro invertebrates to oysters and fin fish. High volume releases create an oceanic plume of colored water and suspended solids extending into the Atlantic Ocean out to the nearshore reef. Together, altered salinity and siltation negatively effect every component of the estuarine and nearshore reef ecosystems, including submerged aquatic vegetation (SAV), phytoplankton, fish and macro invertebrate communities, fish eating birds, reef building polychaetes, and the nearshore reef community (Haunert 1988). The recurring high flow conditions in the SLE have reduced the numbers of oysters dramatically and the frequency at which these high flows occur have prevented recovery that takes three to five years after each prolonged freshet (Cake 1983). Damage to the nearshore reef habitat, especially the chicken-liver sponges, can produce secondary effects on juvenile green sea turtles that feed on the sponges (Browder, personal correspondence 2000). Altered salinity, sudden drops in salinity, or salinity fluctuations are significant stressors to fish and shellfish populations. Lowered salinities and freshwater conditions are conducive to the persistence of fish pathogens, especially fungi, that are found in lesioned fish in the SLE (Landsberg, personal correspondence 2000).

The above problems are exacerbated by the loss and fragmentation of shoreline habitat, by increased inputs of nutrients and dissolved organics and by the input of toxins (Haunert et al. 1994). The loss and fragmentation of habitat due to development results in the direct loss of mangrove wetlands and emergent bank vegetation, upon which fish and macro invertebrate communities depend. Increased inputs of nutrients and dissolved organics degrade water quality, contribute to the accumulation of muck, which in turn covers estuarine hard bottom habitat, and contributes to changes in phytoplankton communities, macro algae, and SAV. Increased input of toxins, from agricultural runoff, urban development and the boating industry, including metals, pesticides and their residues, may lead to bioaccumulation in aquatic food chains leading to fish eating birds. This is one of the factors leading to increased incidence of fish abnormalities in the estuary (Gabriel 1999). A decrease in the numbers, diversity, and health of fisheries can have secondary effects on the health and mortality of the resident dolphin population in the IRL (Browder personal correspondence 2000).

ECOLOGICAL ATTRIBUTES

Nearshore Reef

A nearshore reef forms bands of unique marine habitat two to three miles offshore of the Atlantic Coast between the St. Lucie and Fort Pierce Inlets. This worm-reef, built by Sabellarid polychaetes, is very susceptible to silt and salinity variation. The nearshore reef is the northern extent of nonreef building corals. Shallow reef corals reach their northern limit on inshore rock formations adjacent to the St. Lucie Inlet and Jupiter Island, while inshore rock and Sabellarid and algal reefs proceed further north to Cape Canaveral (Zale and Merrifield 1992, Jaap and Hallock 1991). Major live coral reefs, *Oculina varicosa,* are only abundant on the shelf edges that occur at depth of 60 to 100 meters.

These complex rock, sabellarid, and coral structures create benthic fish habitat diversity on the continental shelf resulting in increased the biodiversity of lagoon fish in the St. Lucie Inlet (Gilmore 1995). Approximately 66% of the seagrass fishes in the lagoon are species that spawn on the continental shelf (Gilmore 1988). Also, the nearshore reef is habitat for juvenile green sea turtles.

The continental shelf fish biodiversity is greatly influenced by various reef structure and sediment. The nearshore reef is adversely affected by high level discharges and the resulting silt and salinity plumes that occur mostly to the south of the St. Lucie and Fort Pierce inlets. (Gilmore, personal correspondence 2000)

Oyster Distribution Health and Abundance

Oysters and other bivalves, such as mussels and *Rangia*, are sensitive to salinity and siltation in the SLE and IRL. Under natural conditions, oyster reefs can be very large and provide extensive attachment area for oyster spat and numerous associated species such as mussels, tunicates, bryozoans, and barnacles (Woodward-Clyde 1998). Several studies (Pearse and Wharton 1938, Wells 1961, Bahr and Lanier 1981) have found from 40 to over 300 faunal species in oyster beds, including other mollusks, crustaceans, annelids, numerteans, flatworms, sponges, coelenterates, and protozoa.

Oysters have been documented in the past as abundant in the estuary and lagoon. Presently their distribution is limited to approximately 200 acres from the estimated historic coverage of 1,400 acres. A restoration target of approximately 900 acres of healthy oyster beds is based on reestablishing a conducive salinity distribution in the areas that provide a potentially suitable bottom habitat as indicated by the St. Lucie Estuary GIS Application Model (Woodward-Clyde 1998). Suitable bottom habitat has soft sediments with little surface structure or roughness.

Work done on oysters in the past document slightly different preferred ranges and mortality thresholds, these various studies are summarized in the 1998 Woodward-Clyde report. The exact thresholds vary depending on age, condition, temperature and other factors. Generally adult oysters require salinity levels above 3 ppt, thrive at 12-20 ppt, and are adversely affected by diseases, predators, and algal blooms at seawater salinity conditions. “Dermo”, implicated as a cause of 50% of adult oyster mortality in Florida, is limited to salinities greater then 9 ppt (Quick and Mackin 1971, Mackin 1962).

Estuarine Benthic Communities

Benthic macro invertebrate communities in the SLE and IRL are sensitive to bottom type, water quality, and salinity fluctuations. A decline in diversity of benthic organisms and the spread of pollution-tolerant macro invertebrates, such as the polychaete worm (*Glycinde solitaria*), is often one indicator of deteriorated water quality in the estuary and lagoon (Beal, personal communication 2000). Furthermore, the fluctuation between periods of high and low discharge causes alternating shifts between estuarine and freshwater species (Haunert and Startzman 1985).

In the Haunert and Startzman study published in 1985, it was found that an overall reduction of 44% of the benthic macro invertebrates occurred during a three-week experimental freshwater release of 2,500 cubic feet per second (cfs). The greatest change in benthic species composition occurred in the newly created oligohaline zone (0.5 to 5 ppt). In this zone, the freshwater midge (*Chironomus crassicaudatus*) increased dramatically. Additionally, six freshwater species were introduced and at least four estuarine species were lost from the shifted oligohaline zone.

Changes in biodiversity and speciation in the benthic communities brought about by restoration is a hard thing to estimate. It is best illustrated in a study in the IRL by Virnstein (1990). He found that at the meter scale, seagrass beds in the IRL can contain three times the density of macro invertebrates found in unvegetated sediments only a few meters away. At a scale of centimeters, two core samples taken next to each other in an apparently homogeneous habitat, often differ in density of macro invertebrates by a factor of two or three (Virnstein 1990).

Salinity Envelop

The estuarine environment is sensitive to freshwater inputs. Modifications to the volume, distribution, circulation, or temporal patterns of freshwater discharges can place severe stress upon the entire ecosystem (Haunert 1994). Salinity patterns effect productivity, population distribution, community composition, predator-prey relationships, and food web structure in the inshore marine habitat. Salinity is the master ecological variable that controls important aspects of community structure and food web organization in coastal ecosystems (Myers and Ewel 1990).

In order to develop an environmentally sensitive plan for the SLE watershed, biological and physical information was needed to determine a desirable range of flows to the estuary. In 1975, South Florida Water Management District (SFWMD) began baseline investigations to determine the seasonal presence of biota and to document the short-term reactions of estuarine organisms under various salinity conditions during controlled regulatory releases and watershed runoff events (Haunert and Startzman 1980, Haunert 1985, Haunert 1987).

In 1987, the SFWMD research began to support the application of a resource-based management strategy similar to the valued ecosystem component (VEC) approach developed by the U.S. Environmental Protection Agency (USEPA 1987) as part of its National Estuary Program. Through this strategy, management objectives are attained by providing a suitable salinity and water quality environment for key species. This approach assumes that environmental conditions suitable for VEC will also be suitable for other desirable species and that enhancement of VEC will lead to enhancement of other species.

Utilizing the application of the resource-based management strategy or VEC approach, a favorable range of inflow and related salinity was established for juvenile marine fish and shellfish, oysters, and SAV (Haunert and Konyha, 2001). This favorable range of flows is referred to as the "salinity envelop". The "salinity envelope" of 350 to 20,00 cfs was established for the SLE based on previous research on fish and shellfish, as well as predicted monthly mean salinity from various inflows at designated areas. A family of curves for salinity in the SLE was obtained by providing a salinity model with constant inflows until a steady salinity gradient was obtained. Using the family of curves, preferred areas, and preferred salinity for oysters and SAV, the salinity envelop can been seen. This provides a method to predict where healthy populations of VEC would exist if the favorable range of flows and salinity is not violated beyond the frequency that is attributed to natural variation of flows from the watershed. A geographic information system (GIS) was utilized to define specific locations within the designated VEC distributions. Factors in addition to salinity that were considered for oysters and SAV included appropriate depth and type of sediment.

Although the initial salinity envelop defined a range of flows desirable for VEC and provided useful flow management guidelines, a more detailed understanding of environmentally friendly flows was needed to develop a watershed management plan. The distribution of flows within the range of desirable flows needed to be defined as well as the "acceptable" frequency of violations of desired range. In other words, the full distribution and timing of flows from the watershed that accounts for natural variation of flows needed to be determined.

Fortunately, recent advances have been made in flow analysis. It is now understood that native aquatic biodiversity depends on maintaining or creating some semblance of natural flow variability and that native species and natural communities will perish if the environment is pushed outside the range of natural variability. Where rivers are concerned, a natural flow paradigm is gaining acceptance. It states "the full range of natural intra- and interannual variation of hydrologic regimes, and associated characteristics of timing, duration, frequency, and rate of change, are critical in sustaining the full native biodiversity and integrity of aquatic ecosystems" (Richter et al. 1997). A similar paradigm is being developed for estuaries. In riverine estuaries, like the SLE, it seems reasonable to evaluate both flows and salinity with respect to their multiple forms of variation. The full range of natural intra- and interannual variation of salinity regimes, and associated characteristics of timing, duration, frequency, and rate of change, are critical in sustaining the full native biodiversity and integrity of estuarine ecosystems (Estevez 2000).

Due to significant improvements in our understanding of SLE watershed flows, estuary salinity, and the need to go beyond establishing a favorable range of favorable flows, a reassessment of the flow distribution for the SLE is required to establish a target flow distribution. SLE watershed flow distribution targets should ensure the protection of the salinity-sensitive biota in the estuary. It is assumed that species diversity in the SLE requires the hydrology to have characteristics of a natural system and that the monthly flow distribution is a critical hydrologic characteristic. Particularly, the frequency of low monthly flows and high monthly flows should be similar to that of a natural system.

Table A-1 summarizes the flow distribution by range of the three "natural distributions" analyzed and used for comparison to the "current condition" as represented by the modeled watershed runoff based on 1995 land use conditions. The Natural Systems Model (NSM) developed for the SLE watershed and the Hydrologic Simulation Program Fortran (HSPF) estimation of predevelopment conditions in the SLE watershed and Peace River represents the natural watershed conditions in the Peace River Florida watershed. (Haunert and Konyha, in preparation, 2001).

Table A-1. List of Natural Flow-Frequency Distributions and the 1995 Base Flow-Frequency Distributions, based on 1965-1995 Climate.

Flow Range		Probability in Each Range (%)			
		NSM (target)	HSPF	Peace River	1995 Base
<350 cfs	<21,130 af/m	54.8	47.6	51.9	31.2
350 to 680 cfs	21,130 to 41,053 af/m	17.7	19.9	20.4	24.2
680 to 1010 cfs	41,053 to 60,976 af/m	6.5	9.7	12.6	12.1
1010 to 1340 cfs	60,976 to 80,898 af/m	6.5	5.9	4.3	8.9
1340 to 1670 cfs	80,898 to 100,821 af/m	4.3	4.0	4.6	7.8
1670 to 2000 cfs	100,821 to 120,744 af/m	3.0	4.8	2.2	4.3
2000 to 3000 cfs	120,744 to 181,116 af/m	4.6	5.9	2.4	7.5
>3000 cfs	>181116 af/m	2.7	2.2	1.6	4.0
Average Annual Runoff (inches/year)		11.3	14.6	10	16.1

Submerged Aquatic Vegetation Distribution, Abundance, and Health

The submerged seagrasses and freshwater macrophytes provide habitat and nursery grounds for many fish and invertebrate communities (Gilmore 1977, 1888a; Gilmore et al. 1981, 1983; Stoner 1983a) and they are food sources for trophically and commercially important organisms (Dawes et al. 1995, Virnstein and Cairns 1986). Other important roles of SAV include benthic-based primary productivity and sediment stabilization (Stoner 1983a, Virnstein et al. 1983, Gilmore 1987, Woodward-Clyde 1998). Seagrass meadows have been described as the marine analog of tropical rain forests because of their structural complexity, biodiversity, and productivity (Simenstad 1994). In the IRL, seagrasses provide the ecological basis for a fishery industry worth approximately one billion dollars a year (Virnstein and Morris 1996).

In a field study conducted by Woodward-Clyde in 1997, the only significant SAV beds in the SLE occurred in the lower estuary near Hell Gate Point. Shoal grass *(Halodule wrightii)* was the dominant species throughout most of this area, with Johnson's seagrass (*Halophila johnsonii)* as the secondary species. The only other documented occurrences of SAV during that study was a very small amount of widgeon grass *(Ruppia maritima)*, wild celery (*Vallisneria americana)*, and common water nymph (*Najas guadalupensis*) in the South Fork of the estuary as well as a small area of widgeon grass in the North Fork. Additional seagrasses that are important in the IRL include three *Halophila* species (including the federally listed *Halophila johnsonii*), *Syringodium*, and *Thalassia*.

In a seagrass change analysis of the SIRL, the 47-mile portion of the lagoon was divided into five segments. A preliminary target of the SWIM seagrass program is to restore and maintain seagrasses to a depth of 5.6 feet lagoonwide (Virnstein and Morris 1996). Between 1992 and 1999, the maximum SIRL seagrass acreage (9,864) occurred in 1996 representing approximately 50% of the target acreage. The lowest acreage mapped during this period occurred in 1999 when seagrass covered approximately 39% (7,808) of the target area. To provide a generalized overview of seagrass health and trends for the entire project area, results for the entire SIRL region are presented in **Tables A-2** and **A-3**. However, trends observed for the SIRL as a whole do not necessarily reflect seagrass health and trends for individual segments. Accordingly, results for each segment are also presented in the tables and discussed in more detail in *Southern Seagrass Change Analysis (*Robbins and Conrad, 2001).

All species of SAV respond negatively to rapidly changing salinity. Decreased light penetration that results from silt, turbidity, color, and phytoplankton blooms further stresses these plant communities. The result has been a decline in the spatial coverage of beds of SAV in the estuary and lagoon (Woodward-Clyde 1998). The St. Lucie Estuary GIS Application Model developed by Woodward-Clyde for the SFWMD in 1998, identifies major areas of the estuary that would be suitable for seagrass establishment were it not for the above impacts. Seagrass loss negatively impacts fish and invertebrate communities. Also, it results in the destabilization of sediments and a shift in primary productivity from benthic macrophytes to phytoplankton, which provide negative feedback to further diminish seagrass beds (Woodward-Clyde 1998).

Table A-2. Southern Indian River Lagoon Seagrass (1986 – 1999) and Seagrass Target Acreage.

Lagoon Segment Number	Total Seagrass Acreage Per Mapping Year						Target Acreage[1]
	1986	1989	1992	1994	1996	1999	
1	-	-	365	341	303	320	324
2	-	-	413	281	136	134	870
3	1,806	1,279	1,513	1,571	1,589	1,520	5,469
4	3,916	4,815	4,273	5,007	5,187	2,856	8,833
5	2,471	2,435	2,310	2,307	2,649	2,978	4,303
TOTAL	8,193	8,529	8,874	9,507	9,864	7,808	19,799

Table A-3. Key Seagrass Change Locations.

Segment	Location	1986 –1989	1989 – 1992	1992 - 1994	1994 - 1996	1996 - 1999
1	West shore of Hobe Sound	No Data	No Data	Losses along deep edge of seagrass beds	Losses in coves	Minimal change
2	Hole in the Wall	No Data	No Data	Major loss	Minor gains	Minor gains
	Great Pocket	No Data	No Data	Losses along east and west shores	Major losses throughout	Minimal change
	Pecks Lake and N. Jupiter Narrows	No Data	No Data	Losses in N.E. corner of Pecks Lake	Major loss in N. Jupiter Narrows and Pecks Lake	Few seagrasses remain in area
	N. Hobe Sound	No Data	No Data	Major loss east shore	Minimal change	Minimal change
3	West Shore Opposite Nettles Island	Major loss	Continued loss	Minimal change	Minimal change	Minimal change
	East Shore South of Nettles Island	Gains and losses	Additional losses	Gains and losses	Additional losses	Gains and losses
	Joes Point	Gains and losses	Minor gains and losses	Minor loss	Major gain	Minor loss
4	East Shore: Bear Point to Herman Bay	Major gain	Minor gains and losses	North end gains; south end losses	Gains offshore; losses near shore	Major loss (most of "loss" area mapped as algae)
	West shore	Major loss along deep edge of seagrass beds	Minor gains and losses	Minor gains	Minor losses	Minor losses and gains
5	West shore: North and South of HBOI	Major gains	Minor losses	Minor losses	Minor gains	Minor gains
	East shore: West of Garfield Cut	Major loss	Minor gain	Minor gain	Minor loss	Minor gains and losses
	West shore across from Ft. Pierce Cut	Major loss	Minor gain	Minor loss	Minor gains and losses	Minor gains and losses

Estuarine Fish Communities/Sport and Commercial Fisheries

The SLE and IRL provide habitats and nursery grounds for a variety of estuarine fish communities (Gilmore 1977, Gilmore et al. 1983). Species richness in many of the fish communities of the estuary and lagoon has declined since the 1970s when baseline data were collected. In addition to the general decline in species richness, specific fish communities appear to be affected by salinity and habitat changes.

Submerged aquatic vegetation communities provide nursery ground habitat for juvenile stages of reef and recreationally important fishes in the SLE and IRL (Lewis 1984, Virnstein et al. 1983). This community includes mutton, yellowtail and lane snappers, yellowtail parrot fish, gag grouper, sailor's choice grunt, tarpon, snook, jack crevele, spotted sea trout, and redfish. The distribution of juveniles of these species indicates the distribution of stenohaline and stenothermic salinity and temperature conditions in seagrass beds. Seagrass loss and alterations in salinity zonation diminish the habitats suitable as nursery grounds for juvenile reef fish species (Gilmore, personal correspondence 2000). Massive freshwater releases from the St. Lucie Canal in the winter of 1998 not only created significant incidences of fish disease and mortality and toxic dinoflagellate blooms, it also reduced the overall biodiversity of estuarine and freshwater fish communities within the IRL for several months following the release (Gilmore personal data and observations along Bessie Cove, IRL, May 1998, relative to Gilmore 1987b, 1988).

The prevalence of diseased and abnormal fish is high in the SLE. Roughly 15% of the fish caught by the National Marine Fisheries Service in the outer estuary and nearshore reef have been visibly abnormal in some way (Browder, personal communication, 2000). The frequency of abnormalities of all types appears to have increased in recent years (Browder et al. 1997, Fournie et al. 1996, Gabriel et al. 1999, Gassman et al. 1994). Although further study, which is currently under way, is needed in order to come to a definitive conclusion, a link between these abnormalities and an increase in the input of toxins including pesticides and their residues is suspected to be a major contributing factor.

Ichthyoplankton recruitment into the SLE and IRL is diminished due to flushing that results from regulatory discharges during key times of the year (Gaines and Bertness 1992). Estuarine fish species that are negatively affected include spotted sea trout, snook, opossum pipefish, and lower trophic level fishes. Snook juvenile settlement rates at specific sites provide a measure of ichthyoplankton recruitment (Gilmore, personal correspondence, 2000). The spotted sea trout is an estuarine-dependant species that is specifically associated with seagrass beds in the estuary and lagoon. Postlarval and juvenile densities in representative seagrass beds, particularly shoalgrass, reflect seasonal salinity and hydrology changes, seagrass bed recovery, and presumably the sports catch of the spotted sea trout (Gilmore, personal correspondence 2000).

The opossum pipefish appears to be an indicator of both estuarine and freshwater conditions in the SLE. Ambient water temperatures and predictable ocean current access limit effective breeding of opossum pipefish populations to the Loxahatchee, St. Lucie, and St. Sebastian rivers of the IRL (Gilmore 1999). The pipefish is presently a candidate for threatened species listing (Gilmore, personal communication, 2000). Adult opossum pipefish live in freshwater bank vegetation, primarily *Polygonum* and *Panicum* beds. Populations at representative sites appear to be indicators of beneficial wet and dry season salinity conditions. Recruitment of the pipefish in the St. Lucie River occurs during a period of low water flow (through May). Therefore, the November winter release of large volumes of fresh water is atypical and likely to have a deleterious impact on juvenile pipefish movement upstream during this period. (Gilmore 1999)

Although harvesting of fish and shellfish by the human population of the region has been shown to extend at least 8,000 years back in time to the Ais and Timucuan Indians, the first commercial fisheries did not develop until the 1890s. In a detailed report done by Woodward-Clyde in 1994, it is noted that a shift in species composition of finfish appears to have taken place with a higher proportion of lower priced species being taken more recently. The increased harvest of species such as menhaden and mullet may also have an effect on the overall ecology and productivity of the lagoon. One species, the spotted sea trout, has shown a steady and significant decline (over 50%) in landing from 1962 to 1988. This species is almost entirely dependent on the lagoon throughout its life cycle, so its decline may be indicative of conditions within the lagoon. Recreational fishing is continually expanding with the growth of both full-time residents and tourists. The number of fishing trips by residents alone increased from 806,067 in 1970 to 1,811,815 in 1990 and is estimated to increase to 2,890,448 by 2010 (Woodward-Clyde 1994).

Shoreline Habitat

Mangrove wetlands, forested floodplain, and the emergent bank vegetation of tributaries of the SLE and IRL support fish and macro invertebrate communities and prevent siltation due to bank erosion. These shoreline habitats have decreased in spatial extent and in function through habitat loss and the loss of connectivity of presently isolated floodplain and shoreline plant communities. A significant portion of the floodplain of the North Fork of the St. Lucie River is completely or partially isolated from the river's main branch because of dredging conducted during the 1920-1940s. The U.S. Army Corps of Engineers dredging operations in the North Fork commenced in 1922 and were proceeded by mapping of the water course (1919) (Dames and Moore, 1996). As a result, certain natural communities including floodplain swamp, floodplain forest, hydric hammock, and oxbows (blackwater river and stream) from the original watercourse are not fully connected to the existing main branch. A significant portion of the river's natural filtration of waterborne nutrients is not utilized to its full capacity. Pilot projects are under way to reconnect mangrove and freshwater wetlands in the IRL and channelized upper reaches of the North and South Forks.

PEFORMANCE MEASURES AND TARGETS

Nearshore Reef

Target: Reduce siltation rates to natural levels on reefs off the St. Lucie and Fort Pierce inlets by reducing the silt carried by freshwater plumes that result from high discharge events from both the SLE watershed and Lake Okeechobee

Target: Reduce salinity fluctuations on reefs off the St. Lucie and Fort Pierce inlets by eliminating the freshwater plumes reaching the reefs that result from high discharge events from both the SLE watershed and Lake Okeechobee

Target: Restore coral, fish, and macro invertebrate community structure and biodiversity of reefs to the conditions documented baseline data collected in the 1970s.

Oysters

Target: Reestablish approximately 900 acres of healthy oyster in the SLE using the St. Lucie Estuary GIS Application Model to indicate areas most likely to support the reestablishment of oysters

Estuarine Benthic Communities

Target: Increase species richness, abundance, and diversity of benthic species to that typically found in a healthy estuarine community

Salinity Envelop

High Flows

Target: Decrease the numbers of occurrences of flows between 2,000 cfs and 3,000 cfs to less than 4.6% of the time

Target: Decrease the number of occurrences of flows greater than 3,000 cfs to less than 2.7% of the time

Low Flows

The modeling shows that the current conditions (1995 base) are within the target range for low flow conditions as predicted by the NSM.

Target: Keep the number of occurrences of flows less than 350 cfs to less than 54.8% of the time

Submerged Aquatic Vegetation

Target: Increase coverage of *Halodule*, *Ruppia*, and *Vallisneria* in the SLE to include all areas (approximately 920 acres) that are indicated to be suitable habitat based on the St. Lucie Estuary GIS Application Model

Target: Increase coverage of beds of *Halodule*, *Ruppia*, *Syringodium*, *Thalassia*, and the three *Halophila* species, including *H. johnsonii*, in the IRL at depths down to 5.6 feet

Estuarine Fish Communities

Species Richness/Diversity

Target: Increase species richness at benchmark locations, such as Bessey Cove to levels equaling or exceeding those in the historic (1970s) database and increase species richness above present baseline conditions in other representative sample sites

Incidence of Abnormalities

Target: Decrease the incidence of all types of fish abnormalities to less than one percent in the SLE and IRL

Juvenile Reef and Recreationally Important Fish

Target: Increase representation of juvenile stages of reef and recreationally important fishes, including the silver snapper species (mutton, yellowtail, and lane), parrot fish, gag grouper, sailor's choice, snook, redfish, and spotted sea trout from present baseline conditions

Lower Trophic Level Fishes

Target: Increase abundance of mullet, menhaden, and anchovy on catch per unit effort to historic (1970s) baseline conditions

Spotted Sea Trout

Target: Increase postlarval and juvenile densities in representative seagrass beds, particularly shoalgrass from present baseline conditions

Snook

Target: Increase juvenile settlement rates of the common and fat snook at representative sites in the SLE from present baseline conditions

Redfish

Target: Increase abundance of juvenile and adult redfish at representative sites in the SLE and IRL from baseline conditions

Opossum Pipefish

Target: Increase populations of adult pipefish, in *Polygonum* and *Panicum* beds of bank vegetation, at representative sites in freshwater tributaries of the SLE, to levels equaling or exceeding those in baseline surveys conducted in the 1970s.

Target: Increase seasonal densities of juvenile pipefish in samples in the SLE

Shoreline Habitat

Target: Increase spatial extent of mangrove and emergent shoreline plant communities through replanting

Target: Reconnect approximately 100,000 linear feet of isolated river floodplain and remove and control exotics on the reconnected floodplain

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